Evolution of microstructures in high and low Ti/Al ratio ferritic stainless steels after hot rolling

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Abstract. The evolution of microstructures after hot rolling was studied on high and low Ti/Al ratio ferritic stainless steels. The steels were hot rolled using the Gleeble 1500D® thermomechanical simulation machine. The evolution of the microstructures was compared using the electron backscattered diffraction (EBSD) mode of scanning electron microscope (SEM) and optical microscopy (OM) methods by studying the grain sizes and recrystallization after hot rolling. The results showed that after hot rolling, the grain structure of the high Ti/Al ratio steel was more pancake like and smaller with high volume fraction of recrystallized grains. These recrystallised grains were mostly localised around TiNb(C,N) particles, which suggested particle stimulated nucleation (PSN) of grains. It was therefore seen that PSN occurred in both steels and therefore there was supposed fine grains and improved texture in both steels but the initial grain size prior to deformation overrides the effect of occurrence of PSN. Starting deformation with fine grained material yields higher recrystallization microstructures and textures.

1 Introduction

In modern uses of stainless steels, strength and corrosion resistance are important properties [1]. Due to their cost advantage in the steel market over the other grades of stainless steels, ferritic stainless steels (FSSs) have attracted interest in the industrial, economic and academic sectors as one of the alternatives [2, 3]. However, these grades of stainless steels are susceptible to developing an unattractive surface flaw commonly known as ridging that degrades aesthetic qualities of the steels [4]. This usually occurs after deep drawing and forming processes [5]. One way of studying the depth to which this surface flaw may affect the material is to study the evolution of the microstructures and texture after thermomechanical processing (TMP).

The 441 FSS passes through little to no phase changes during solidification and downstream processing [6]. Therefore, without the ferrite to austenite transformation it is not easy to achieve grain refinement by only relying on the recrystallization during hot rolling. FSSs are known for columnar cast structures. During hot rolling, these columnar grains form elongated deformation bands with subgrains. In high stacking fault energy BCC metals such as 441, cross slip and climb of these dislocations occur quite easily, which promotes dynamic
recovery instead of dynamic recrystallization making it difficult to achieve grain refinement [7]. Hence ways of achieving grain refinement include controlling the rolling parameters such as temperature, strain rate and strain [8]; deformation around particles (these particles are high strain points which become deformation zones for grain evolution) [9-10]; and starting deformation with finer grains [11].

According to reports, the formability of FSSs is enhanced when the sample exhibits strong {111} recrystallization textures [12]. Strong {111} recrystallization textures are related to the uniform grain structure distribution [13]. This means that when the grains structure is uniform throughout or in major portions of the sample, the intensity of the {111} recrystallization texture will be improved. The {111} recrystallization texture which is the γ-fibre texture [14] is therefore the preferred texture due to the improved formability reported in various researches when higher intensities of this texture is obtained [15-16]. In this study, the effect of hot rolling on the evolution of microstructures, grain size, texture and recrystallization were studied. Also, the changes in the hot rolling finishing temperature and its effect on the microstructures, grain size are discussed.

2 Methodology

The chemical composition of investigated steel in mass% was 0.013-0.015C, 0.5-0.54Si, 0.29-0.4Mn, 17.58-17.71Cr, 0.018-0.02N, 0.162-0.18Ti, 0.389-0.394Nb, 0.023Al and 0.068Al for the high and low Ti/Al ratio steels. The steels were received in as-cast condition from Columbus Stainless Pty. Ltd. The steels were designated as high and low Ti/Al ratio to depict steels with 0.023 and 0.068 mass% Al respectively. Figure 1 shows the as-cast microstructures for both steels. Prior to hot deformation simulations using the schedule shown in Figure 2 on Gleeble 1500D™ thermomechanical simulator in pure argon (Ar) environment to prevent oxidation of samples, the samples were soaked at 1250 °C for 24 hrs to grow the grains to 1760 and 2400 µm for the high and low Ti/Al ratio respectively. In Figure 3, the microstructures after soaking at 1250 °C were observed by optical microscopy (OM). Electron backscattered diffraction (EBSD) mode of SEM was then used to study the deformed samples. The EBSD measurements were conducted using accelerating voltage of 20 kV, working distance of 16-21 mm and step size of 0.5 µm. All microstructural characterisation (EBSD and OM) were performed in the plane of the rolling-normal directions (RD-ND).

![Figure 1](image1.png)

**Figure 1:** As-cast macrographs (a) high Ti/Al ratio, and (b) low Ti/Al ratio
3.1 Evolution of the microstructures after TMP simulation

Figure 4 shows the evolution of the microstructures after hot rolling and finishing at 1000, 900 and 800 °C. As may be seen for all three finishing temperatures FTs, the high Ti/Al ratio steel was more deformed as seen by the pancaking of the grains in the rolling direction. Hence high Ti/Al ratio steels are easily softened by the application of temperature and thereby easily deformed by the application of strain to the sample [17].
Figure 4: Microstructures of hot rolled samples (a)-(c) high Ti/Al ratio steel from high - low rolling finishing temperature, (d)-(f) low Ti/Al ratio steel from high - low rolling finishing temperature.

Figure 5 and Figure 6 show the inverse pole figures (IPF) maps and misorientation maps respectively. It can be seen that both steels exhibited partial recrystallization after hot rolling, which is common in FSSs [18,19,20]. For both steels, at a FT of 1000 °C, the grains are less pancaked due to the high recovery rate and the converse is true at lower temperatures, i.e. at 800 °C [21]. However, the steel with the initial grain size of 1760 µm, showed finer microstructures at all FTs. Therefore, it can be stated that the influence of the initial as cast structure shown in Figure 1, which is influenced by the Ti/Al ratio is retained even after soaking for 24 hrs at 1250 °C (shown in Figure 3) and hot rolling simulations. This implies that irrespective of the difference in the volume fraction and species of the inclusions and precipitates after soaking, Figure 7, the evolution of the microstructures during hot working is by and large dependent on the initial grain size, Figure 3. In other words, while particle stimulated nucleation (PSN) was evident in both steels as shown with black arrows in Figure 8, its impact could not override the influence of the initial grain size.

Figure 5: IPF maps from EBSD analysis (a)-(c) high Ti/Al ratio steel from high - low rolling finishing temperature, (d)-(f) low Ti/Al ratio steel from high - low rolling finishing temperature.
Figure 4: Microstructures of hot rolled samples (a)-(c) high Ti/Al ratio steel from high-low rolling finishing temperature, (d)-(f) low Ti/Al ratio steel from high-low rolling finishing temperature.

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Figure 6: Misorientation maps from EBSD analysis (a)-(c) high Ti/Al ratio steel from high-low rolling finishing temperature, (d)-(f) low Ti/Al ratio steel from high-low rolling finishing temperature.

Figure 7: Inclusion study for reheated steels (a) number density distribution, (b) and (c) distribution of Ti-based oxides in high and low Ti/Al ratio steel respectively.
Figure 8: Activity of PSN in (a) high Ti/Al ratio steel, (b) low Ti/Al ratio steel

3.2 Evolution of texture after TMP simulation

Figure 9 shows the evolution of the texture after hot rolling and finishing at 1000, 900 and 800 °C. As may be seen from the $\theta=45^\circ$ section of the orientational distribution functions (ODFs), high Ti/Al ratio steel exhibited the $\gamma$-fibre texture whereas the low Ti/Al ratio steel exhibited the cube texture. However, as the FT decreased in both steels, the intensity of the $\gamma$-fibre texture increased. This is mostly reported in deformed FSSs and it is attributed to the increased recrystallization process [22]. The higher intensities of the $\gamma$-fibre implies that there is high recrystallization in the sample and thereby the formability of the steel is improved. This is what most manufacturers and ferritic stainless steel industries seek to achieve [23,24].

Figure 9: ODF maps (a)-(c) high Ti/Al ratio steel from high - low rolling finishing temperature, (d)-(f) low Ti/Al ratio steel from high - low rolling finishing temperature

4 Conclusion

In this study, the evolution of the microstructures in the high and low Ti/Al ratio steels was investigated after various hot rolling finishing temperatures and the following conclusions were drawn:
• The high Ti/Al ratio steel exhibited more recrystallization and grain refinement as a result of initial grains prior to deformation being fine. These fine grains were mostly broken down into various cells which subsequently combines to form grains.

• The high Ti/Al ratio steel exhibited higher intensities of the more preferred γ-fibre texture after hot rolling, which was attributed to the higher recrystallized fraction. This implies that high Ti/Al ratio steels would yield improved formabilities.

• As expected, PSN was observed in both steels but its influence could not override the initial grain size prior to the hot TMP simulations. High Ti/Al ratio steels which was made up of fine grains in the as-cast state was seen to yield finer microstructures after deformation.

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References